# Assessing Industrial Nuclear Reactor Risk using Incident Reporting Risk Matrix Method

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**Abstract - This novel study assessed industrial nuclear reactor risk using incident reporting risk matrix. It has also investigated the dangers, causes leading to dangers and their effects and it has identified the occurrence possibilities and intensity of consequences. Moreover, risk levels have been obtained. It was found that 17%, 61%, and 22% of the risks were unlikely, weak, and possible, respectively. The same are 26%, 39% and 35% of the hazards with moderate, major and severe consequences, respectively. Also, according to the risk matrix, 4%, 26% and 70% of the risks have low, medium and high levels of risk, respectively. Those risks having the risk level of high, were in need of control and preventive actions. Due to this reason, control and preventive actions suitable with consequences and risk effects were proposed and presented. These control and preventive actions were generally placed in the design phase including thermal design, hydraulic design as well as process control.**

**Keywords:** Risk assessment, Nuclear reactor, Incident reporting risk matrix

## 1. Introduction

Human societies` need toward reliable energy resources for sustainable development and increasing global sensitivity regarding the reduction of environmental pollutions specially radioactive materials have lead the research be accelerated in the field of nuclear studies [1]. Nuclear reactor refers to equipment in which nuclear chain fission reaction is done continuously and through being under control. In a nuclear reactor, neutrons are used for heavy nuclear fissions. Heavy nuclear fission leads to the production of lighter nuclear, thermal energy and various neutrons. Nuclear reactor not only includes purified nuclear fuel networks, but also includes fuel cooling system during chain reaction simultaneous with energy production such that constituent materials of heart not be damaged structurally [2]. The heart of a nuclear reactor includes some integrated fuels, each of which is consisted of some holder fuel bars and liquid cooling networks [3]. The most important application of nuclear fission reactors is in huge nuclear power plants. The output of nuclear reactor is water vapor with a high pressure and temperature. This vapor produces electricity through rolling turbine and finally generator. Security aspects are of utmost importance, since we should care about the dangers of radioactive materials [2]. Risk is an inevitable factor in projects that if ignored or not managed properly, it would be impossible to control the circumstance [4]. Risk assessing is a versatile method for managing effective equipment in security processing units to reduce the risk resulting from various events. Nowadays, using risk assessing methods have a growing speed and various methods are used for identifying the dangers and risk assessing [5]. Risk assessing is a logical method for investigating the dangers focusing on identifying the dangers and their potential consequences on the individuals, materials, equipment and environment. In fact, by doing so, valuable data for decision making is obtained which mainly includes reducing danger risks (through control and preventive actions), planning for emergency conditions, acceptable risk levels, inspection and keeping policies in industrial installations [6]. In this research, assessing industrial nuclear reactor risk has been investigated for the first time using incident reporting risk matrix method.

## 2. Methodology

To assess the risks, incident reporting risk matrix method has been utilized.

Remembrance 1: Risk assessing should be conducted by two perspectives of the possibility of risk occurrence in the future according to the guidance Table 1 as well as its consequences on the purposes as stated in the guidance Table 2.

Guidance Table 1: The possibility of risk occurrence in the future

| **Possibility percentage** | **Occurrence possibility** |
|---|---|
| Less than 1% | Rare |
| 1%-20% | Unlikely |
| 21%-50% | Possible |
| 51%-90% | Likely |
| More than 90% | Almost certain |

Guidance Table 2: Risk occurrence consequence in the future

| **Explaining the consequence of risk occurrence** | **The intensity of the consequence** |
|---|---|
| It has an insignificant effect on the purpose of nuclear reactor*. | Insignificant |
| It has a minor effect on the purpose of nuclear reactor. | Minor |
| It has a moderate effect on the purpose of nuclear reactor. | Moderate |
| It has a major effect on the purpose of nuclear reactor. | Major |
| It has a severe effect on the purpose of nuclear reactor. | Severe |
| *In industrial measurements, the purpose of nuclear reactor is producing energy (electricity energy). | |

Guidance Table 3: Risk prioritizing

| | Consequence Intensity | | | | | |
|---|---|---|---|---|---|---|
| | Status | insignificant | minor | moderate | major | Severe |
| Likelihood | Almost certain | Medium | High | High | Severe | Severe |
| | Likely | Medium | Medium | High | Severe | Severe |
| | Possible | Low | Medium | Medium | High | Severe |
| | Unlikely | Low | Low | Medium | High | High |
| | Rare | Low | Low | Low | Medium | High |

Table 4: Guidance table for the risks

| **Actions** | **Guidance for accepting the risk** | **Risk status** |
|---|---|---|
| Immediate actions should be taken to eliminate the risk source. | Not acceptable | Severe |
| If possible, actions should be taken in near future to control the risk. | Generally not acceptable | High |
| If possible, action should be taken in far future to control the risk. | Generally acceptable | Medium |
| Informing related individuals about the existing risk and applying more observance | Acceptable | Low |

## 3. Results and discussions

The table of identifying and assessing as well as controlling risks have been specified and presented below.

Table 5: Risk assessing table using incident reporting risk matrix method

| Identifying, assessing and controlling the risk | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Row** | **Risk** | | | **The level of occurrence possibility** | **The intensity of the consequence** | **Risk status** | **Suggestive actions) control and preventive actions)** |
| | **Reasons** | **Event** | **The consequence on the purpose of nuclear reactor** | | | | |
| 1 | Creating deficiency or disorder in the cooling system | Incorrect energy balance among energy production and cooling rate | Constituting materials of the heart of the reactor are damaged in terms of structure and geometry. | Unlikely | Major | High | Designing and using cooling intelligent control system |
| 2 | Sudden turn off of the nuclear reactor | Increase of reactor`s heart temperature due to the continuance of decomposition heat of fission radioactive products | Melting and deteriorating fuel elements | Unlikely | Major | High | Design and application of materials in fuel elements that are highly resistant to severe temperature shocks |
| 3 | Inappropriate design of the reactor | Unbalance of losing neutron rate due to absorbing and leakage with the production rate of neutron | Not having sustainable chain reaction and as a result, not having a constant energy production rate | Unlikely | Major | High | Engineered and exact designing of the reactor |
| 4 | Melting and collapse of nuclear reactor`s heart | Induction of high positive reactivity | Releasing high energy (small nuclear explosion) | Rare | Severe | High | Exact and engineered thermal designing of the reactor |
| 5 | Complete exit of control bar with the highest radioactive value | Significant deviation in the spatial independent of time figure | Invalidity of synthetic-point model | Rare | Medium | Low | _ |
| 6 | Retarding neutrons of fission | Low error in the intensity absorption regarding nuclear such as $U^{238}$ and $Th^{232}$ | High error in estimating fuel consumption and changing the fruitful materials of $U^{238}$ and $Th^{232}$ to fission $Pu^{239}$ and $U^{233}$ | Possible | Major | High | Exact and correct designing of the kind and measure of neutron retarding in the reactor |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | Error of thermal designing in the heart of reactor | Increasing heart temperature of the reactor, more than melting temperature of heart components | Melting reactors` heart components (specially fuel and sheath) | Unlikely | Major | High | Exact and engineered thermal designing in the heart of the reactor |
| 8 | Having fault in designing consecutive processes of thermal energy transferring resulting from nuclear fission | Rapid temperature increase in the sheath | Boiling of cooling liquid | Unlikely | Moderat e | Mediu m | – |
| 9 | Error in hydraulic design in the heart of the reactor | Increase of loss of cooling pressure while crossing over the heart of the reactor | Increase of hydraulic pressure on the heart of the reactor components and as a result, increasing pumping costs | Unlikely | Moderat e | Mediu m | – |
| 10 | Fuel`s long resistance in the heart of the reactor | Failure of fuel elements | Increase of the possibility of radiation dangers | Unlikely | Severe | High | Exact designing of the fuel retention time in the heart of the reactor |
| 11 | Weak conduction of nuclear fuel (Oxide or Uranium Carbide) | High temperature changes in nuclear fuel elements | High thermal tensions to fuel elements | Rare | Major | Mediu m | – |
| 12 | -Breakage of fuel sheath -Breakage in the cooling system of heart (pipe) – Damaging the case of heart of the reactor | Release of radioactive materials | Highly negative physical and environmental effects | Unlikely | Severe | High | Rapid control systems for tuning off the reactor in accident conditions |
| 13 | Differential expansion | Bucking fuel bar | Having instability in some of the designs of the heart of the | Unlikely | Moderat e | Mediu m | – |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | reactor | | | | |
| 14 | Fuel ray | Creating inflation in the fuel | Creating pressure on the sheath | Possible | Moderate | Medium | – |
| 15 | Gas productions of fission | Having pressure on the sheath | Form change of fuel bar in high temperature (Jumping to high temperature) | Possible | Moderate | Medium | – |
| 16 | Temperature changes | Huge thermal slopes in the symmetry line of fuel needle to the sheath | Breakage of the sheath in the radiation environment of the heart of the reactor | Possible | Major | High | Designing and constructing sheath from materials having high resistance against thermal changes |
| 17 | Reactor`s turning on and off | Temperature changes occurring while turning on and off the reactor | Breakage of the sheath in the radiation environment of the heart of the reactor | Possible | Major | High | Designing and constructing sheath from materials having high resistance against thermal changes |
| 18 | If the AC electricity of the cooling system of the reactor and supporting diesel generators not work and reactors be put against severe dangers of extreme heat without having cooling system | A hot nuclear of a reactor, without having a permanent resource of cooling materials, continuously vapors the water around fuel bars to the extent that fuel bars are placed above water level. In case fuel bars are places above the cooling materials, they may be melted and the hot radioactive fuel may remain in the store having reactor. | In the worst state of melting, the mixture of melted fuel is melted by metal case, disposing alternative amounts of radioactive radiations against out world through crossing over later obstacle that are designed for keeping nuclear materials. | Unlikely | Severe | High | Pumping the water having various mineral component to the inside of the nuclear of the reactor along with the injection of Boric acid as the absorbent of neutron to the inside of the reactor |
| 19 | Zirconium reaction of fuel bars with the cooling water in a high | Gathering of produced hydrogen resulting from the reaction | Destruction of outer walls of the reactor due to the exploitation | Unlikely | Severe | High | Designing intelligent thermal control system for the reactor |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | temperature | | | | | | |
| 20 | Reducing the cooling water level | Placement of fuel bars outside of the water level | Severe damage to fuel bars | Unlikely | Major | High | Using intelligent controllers for controlling the cooling water level |
| 21 | Impairment of the cooling system along with operator`s faults | Melting of Reactor core | Exiting some of the dangerous radioactive radiations from the reactor | Unlikely | Severe | High | Using assisting cooling system that the time a fault happens in the main cooling system, it intelligently and automatically, it circulates the cooling fluid, and prevents nuclear reactor`s melting. |
| 22 | Impairment of the cooling pumps of the reactor | - Reactor`s nuclear melting<br>- High temperature of the center of the reactor<br>- Destruction of fuel bars of the reactor | Distributing radioactive materials | Unlikely | Severe | High | Using assisting and supporting pumps that are automatically entered to the orbit the time main pumps are not working, so they circulate the cooling liquid. |
| 23 | Meltdown of the central part of the reactor | Melting atomic fuel cylinders and other parts of the reactor | High leakage of radioactive materials to the surrounding environment and high pollution | Rare | Severe | High | Exact thermal designing of the reactor |

Table 6: Possibility percentage share of various risks

| Row | Possibility occurrence level (%) | Kind |
|---|---|---|
| 1 | 17 | Rare |
| 2 | 61 | Unlikely |
| 3 | 22 | Possible |

Table 7: Intensity of consequences` percentage share regarding various risks

| Row | Intensity of the consequence | kind |
|---|---|---|
| 1 | 26 | Moderate |
| 2 | 39 | Major |
| 3 | 35 | Severe |

Table 8: Levels` percentage share of various risks

| Row | Risk level (%) | Kind |
|---|---|---|
| 1 | 4 | Low |
| 2 | 26 | Medium |
| 3 | 70 | High |

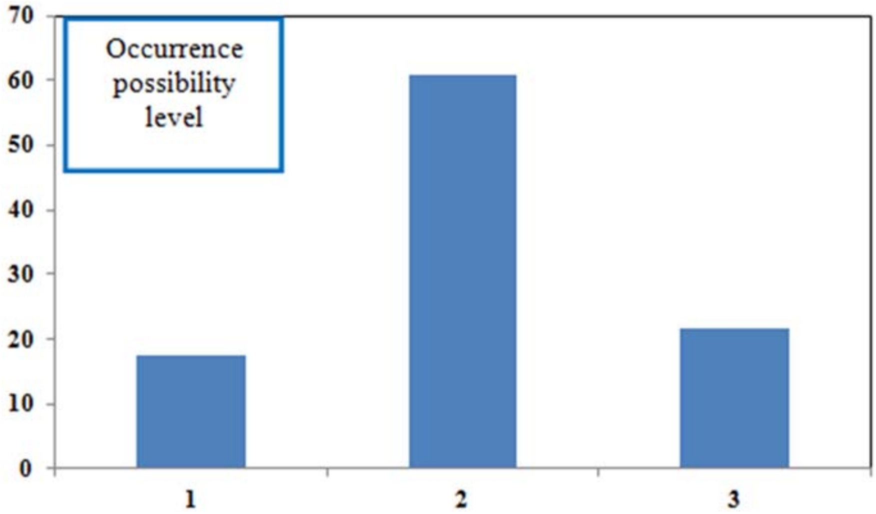


Figure 1: Occurrence possibility level for various risks (%)

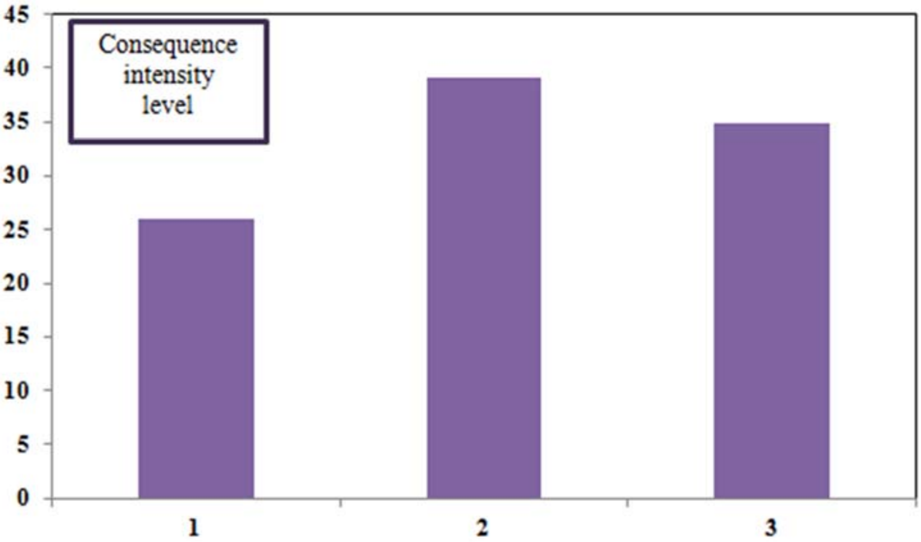


Figure 2: Consequence intensity level for various risks(%)

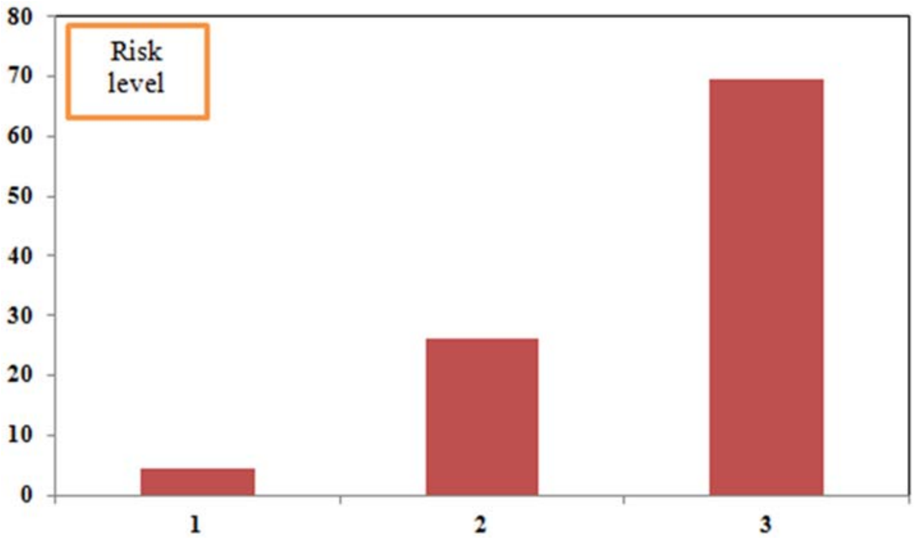


Figure 3: Risk level for various risks (%)

According to Table 5, based on incident reporting risk matrix method, 23 important dangers with dangerous factors and consequences as well as related effects were identified.

It was revealed that 17%, 61% and 22% of dangers had the occurrence possibility of rare, unlikely and possible, respectively (Table 6, Figure 1); this means that most of the risks had the occurrence possibility of unlikely and possible (83%). Accordingly, 26%, 39% and 35% of dangers had the consequence intensity of moderate, major and severe (Table 7, Figure 2); this means that most of the risks had the consequence intensity of major and severe (74%), which is due to the nature of the reactor (nuclear reactor) and its related consequences. Considering risk matrixes, 4%, 26% and 70% of the dangers had a risk levels equivalent to low, medium and high (Table 8, Figure 3). 8 risks had the occurrence possibility, consequence intensity and risk level equal to unlikely/rare (6 of them were unlikely and 2 of them were rare), severe and high. These were more severe than others. These types of risks were related to the risks and consequences of these effects, including radioactive radiation and the emission of hazardous radiation to the environment and the highly hazardous (human and environmental) damage caused by them and the same explosion in the reactor due to damage to the internal wall caused by the explosion of the nuclear reactor. 16 group of risks needed control and preventive actions. Risks having risk levels of high, needed control and preventive actions. Therefore, control and preventive actions suitable with consequences and risk effects were suggested and presented (Table 5). These control and preventive actions generally included designing and using appropriate material in fuel elements, using appropriate neutron controllers, accurate thermal designing according to heat transfer principles, exact designing of the fuel retention time and appropriate design of the fuel sheath (in terms of material, structure and geometrical form). Moreover, control actions` discussion includes reactor control systems in accident conditions, controlling reactor temperature, controlling cooling water`s level as well as appropriate and intelligent designing in the cooling system of the reactor.

## 4. Discussion

This study was conducted with the aim of analyzing industrial nuclear reactor`s risk. It was revealed that control and preventive actions are of utmost importance in the designing phase. The first and dangerous responsibility of nuclear reactor`s design of the heart is taken by nuclear engineer. Various aspects of designing such as thermal-hydraulic design, structural and geometrical design are important. It includes designing indexes, applicable discussions, reliability, security and etc. As it was indicated in the risk assessing table, in case errors take place in nuclear reactor`s design and process, various dangers and consequences resulting from that as well as irreparable effects would happen in nuclear reactor process. Risk assessing is a powerful and capable instrument for avoiding and preventing such dangers and their consequences.

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